CLIMATIC AREAS OF THE UNITED STATES AS RELATED TO PLANT GROWTH.[1]

(Plates IX, X, and XI.)

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Introduction.

The climatic factors which generally determine whether a given kind of plant may or may not live in a certain locality are to be divided into two groups. The first group comprises those factors which tend to increase or to decrease the moisture content of the plant body. They may be termed the moisture conditions of the environment. The second group includes the climatic factors which tend to raise or to lower the temperature of the plant. These are the temperature conditions. A third group of climatic factors includes those tending to increase or decrease the insolation of the plant and hence to promote or retard photosynthesis in green tissues, by which carbon dioxid and water are decomposed with the formation of molecular oxygen and carbohydrate. With these light conditions, however, climatic plant geography has as yet but little to do and this group will not receive attention in the discussions which follow.

Before plant geography can pass beyond its qualitatively descriptive phase, the moisture and temperature relations that obtain between plants and their surroundings must be subjected to examination much more quantitative than has heretofore been attempted. As in other similar instances, definite knowledge of this complex set of relations can be reached only through measurements of the things that are to be related. It thus appears that, for those chapters of plant geography and of scientific agriculture which have to do with climatic conditions, it will presently be found requisite to

[1] Botanical contribution from the Johns Hopkins University, No. 32.

measure both the plants dealt with and their environmental conditions. Since both plants and their surroundings are always changing, it is essential that our measurements take the form of summations or integrations. It is therefore first incumbent upon us to find means of integrating or summing the various fluctuating conditions, within and without the plant body, that determine the development of the organism and that decide whether it can exist at all in any given set of surroundings.

Measurement and summation of conditions within the plant.

Our very meager knowledge of plant dynamics would render quite hopeless, for the present, any attempt to integrate the qualities, intensities and durations of physiological processes, were it not for the fact that the plant itself furnishes at any instant a very clear and unequivocal summation of the effects of all the processes which have gone on in its body during its previous developmental history. This fact furnishes the criterion by which comparisons have usually been made between the growth processes of different kinds of living things. The amount of growth accomplished during a given time period may be determined by weighing the crop or some portion of it, a method commonly in use in agricultural studies. Another method, employed mainly by phenologists, has been to determine the length of time which may elapse during certain developmental phases of the organism. Thus may be determined the length of the time period that intervenes between seed germination or the first swelling of lead buds, and flower production or the ripening of fruits. Still more simple and more easily applied is the method which merely determines whether or not given plant forms are able to carry out their life cycles under the environmental conditions of certain localities. For the positive answer to this question mere observation frequently suffices, for its negative answer, experimentation, or at least instrumentation, is necessary. If a plant form is observed as thriving year after year and generation after generation in a certain locality, it is, as has been mentioned elsewhere, no less than redundant to point out this as an "adaptation"; but if the given form is not to be observed in this locality, the most direct and final way to determine whether or not it can thrive there, is actually to make the experimental test.

Frequently a simple inspection of the plant dealt with, or the approximate measurement of certain of its characteristics, may suffice for an indication of its ability to withstand the water-withholding or water-extracting power of the environment. Thus, it has long been appreciated that the ability of a plant to thrive under arid conditions is often indicated by its observable physical structure. The power of an organism to withhold moisture from an arid environment seems to be closely, and usually directly, connected with structural characters which can be recognized at sight, and, on the basis of this principle, ecologists have classified plants into xerophytes, mesophytes and the like. Of course this classification must be subjected to a much more definitely quantitative treatment than the one now generally employed, that of mere observation and personal judgment, before ecology can begin to partake of the characters of an exact science. For such a resurvey of the moisture-retaining powers of plants we have now at least two practicable and fairly quantitative methods[1a] besides the directly experimental one of trying various plant forms under various climatic complexes. This is not the place to enter into a consideration of these methods, but it should be emphasized that it now appears to be possible, within a single period of twenty-four hours, to determine with considerable accuracy the position of almost any plant individual in what might be termed an absolute scale of xerophytism, as far as the water-withholding power of its aerial parts is concerned.

For the study of the effects of temperature conditions within the plant, no means is yet available excepting that of direct experiment. In one way the problem here met with is simplified by the well-known fact that plant temperatures practically always follow very closely the temperatures of the surroundings. In attempts to determine the relations between temperature and the various plant processes, it is therefore only necessary to know the effective temperature condi-

[1a] Livingston, B. E., "The Resistance Offered by Leaves to Transpirational Water Loss," *Plant World*, 16: 1–35, 1913. Also references there given.

tions of the environment and it is seldom requisite to study the temperature of the plant body separately.

The ability of a plant to withstand unfavorable temperature conditions, quite unlike its ability to withstand adverse conditions of the moisture relation, is not at all indicated by structural characteristics. It is absolutely impossible by mere observation or by any morphological study of a plant, to find a basis even for a rational guess as to the temperature conditions to which the organism may be fitted. Furthermore, no method but that of direct experimentation has been devised, and none seems likely to be forthcoming, by which plants may be studied with regard to their temperature requirements, and the appreciation and interpretation of direct experiment is here so extremely complex that scarcely any attempt has thus far been made in this direction. The result is, that, while we are well aware that temperature conditions are fully as important as those of moisture, in determining plant development and distribution, yet we are without any really quantitative knowledge of the heat relation.

Before such quantitative knowledge can be attained it will be necessary that there be made available somewhere a laboratory so equipped that all of the main conditions of plant growth may be controlled and altered at the will of the experimenter. The need of such a laboratory has been emphasized by A. de Candolle and again by Abbe,[2] who also quotes de Candolle, but, so far as I am aware, no serious attempt has ever yet been made to procure facilities for adequate experimental study of the range of conditions which various plant forms may be able to withstand. The value of such a laboratory to scientific agriculture cannot be overestimated.

For both the temperature and moisture limits of plant activities, a kind of rough and qualitative experimentation has studied the growth of the same variety of plant in different localities or of different varieties in the same locality, and has drawn volumes of vague and more or less discordant conclusions without adequate measurement either of the plants employed or of the climatic conditions to which they have been subjected. This sort of experimentation is

[2] Abbe C., First report on the relations between climates and crops. U. S. Dept. Agric. Weather Bureau Bulletin 36, 1905. See especially p. 23.

very common to-day, especially among agricultural institutions, and considerable practical information is no doubt resulting therefrom. In this agricultural work, however, as also in the observational studies upon natural vegetation, with which plant ecologists are so generally engaged, the physiological characters of plants are determined almost solely with reference to the locations at which they grow. Thus, seedsmen, to describe the physiological properties of the plants with which they deal, must name the regions in which these plants succeed. "A greatly approved variety among the truck gardeners of Long Island," "one of the most successful earlies throughout the South."—so run such trade descriptions.

Measurement and summation of environmental conditions.

When we describe the physiological capabilities of a given strain or species by stating the geographical region in which it thrives, we are of course employing the environmental conditions as a unit for measuring and defining the internal ones. Valuable as this sort of definition undoubtedly is, it falls far short of perfection, even for practical purposes. The climatic conditions of any locality vary from day to day throughout the year and their annual march is never the same for different years. An agricultural plant that proves very successful for one season in a certain place may be a complete failure for the following year. It is clear, therefore, that we must seek methods for describing climatic conditions, other than their simple reference to certain geographical regions. If such methods can be devised, even though we may have no better ways of characterizing our plants than are already at hand, it should become possible to compare the environmental conditions of different regions, and plant geography, as well as scientific agriculture, should be greatly advanced.

Methods and Data.

Turning now to the consideration of the methods which are at hand for comparing climates, we are struck with an amusing fact; the most intelligible and most widely used way to do this is to characterize the climatic conditions of any region in terms of the kinds of plants and animals which thrive there. The sage-brush is a plant with physiological characters such that it thrives best in the temperate arid regions of North America, and the climate of these regions is such as to render sage-brush the dominant and characteristic form of plant life. So we reason in a circle and arrive nowhere.

There are, however, instrumental methods more ideal, if not more satisfactory, by which climates may be compared. Thus the averages or means of temperature, precipitation, humidity, etc., of the meteorologists and climatologists, give numerical data which are, in a way, descriptive. It appears, indeed, that means or averages of the climatic data which have been and are being accumulated throughout the world should furnish a numerical basis for distinguishing between different climatic areas, and this basis has of course been employed by climatologists for many years. Ecologists and agriculturists have frequently made use of such climatic means and have so described the climates with which they have had to deal. But if you will look over any of the recent ecological papers you will find that the definition of climates has not gone very far. Usually a section of such a paper is devoted to the characterization of the climates of the areas considered, but the quantitative part of this section is little more than a mass of unrelated figures; out of these the author himself seems to make no serious attempt to draw generalizations that may be related to the corresponding vegetational areas.

We are thus confronted with a state of affairs which is far from satisfactory. The weather services of the world are expending vast amounts of wealth and energy in accumulating, year by year, observational statistics bearing upon the various climatic areas. These statistics are largely used for weather prediction and for the purposes of theoretical meteorology. It seems that quantitative climatic descriptions must lie hidden somehow in these enormous masses of figures, but the plant geographer, whether agriculturist or ecologist, has thus far been able to derive therefrom but a very small amount of applicable information.

It seems to me that the reason for this state of affairs is a double one: first, the climatological observations of our weather services have been planned and are carried out mainly not for the study of climate as it may influence plant growth but for the study of meteorology and climatology and for weather prediction; second, the methods now employed for handling the observational data after they have been obtained are not well suited to the study of the climatic relations of plants. To make these propositions clear, we may consider the work of the United States Weather Bureau, this work being familiar to all of us and having a direct bearing upon the problems of plant distribution as I have been led to attack them. Although the Weather Bureau is officially a part of the national Department of Agriculture, being one of the largest bureaus of that department, its main activities have neven been primarily directed towards the relation between agriculture and climatology. Weather prediction and weather history seem to have been almost the sole scientific aims of the organization up to the present time. The student of plant activities will find no fault with these aims, but he may wonder how it has come about that an agricultural bureau has so thoroughly ignored what we must regard as by far the most important relation which exists between human welfare and climate; that is, the relation between plant growth and the climatic features of plant surroundings.

As to the making of climatic observations, it is clear that observatories in the rural districts are the only ones whose records are properly available for our present purposes. It is a curious fact which speaks for the political or commercial rather than scientific nature of our Bureau's organization, that the best equipped observatories in this country are generally located in large cities, and usually high in the air. As the population of the United States has increased you may note a somewhat parallel increase in the average distance of the climatic observatories from the ground. This of course ought not to be. If political and commercial interests demand observatories in the urban districts the records from these should be treated only as special studies of special conditions. It is interesting to note that the charts of Day's[3] recent bulletin upon frost data have

[3] Day, P. C., "Frost Data of the United States," etc., U. S. Dept. Agric. Weather Bureau Bulletin V, 1911.

been compiled, as the author states, wholly from the observations of rural stations. The requisite stations must be, however, in the open country, and not even in small towns.

Furthermore, the geographical distribution of Weather Bureau stations in the United States is anything but rational. Being located mainly in large cities, these stations cluster thickly east of the Mississippi River and are widely separated in the western half of the country. Such an arrangement has, no doubt, its political, commercial, financial and historical reasons; nevertheless, it is scientifically quite the opposite of rational, for climatic gradients are gentle in the east and very abrupt in the west.

For the purposes of the student of vegetational-climatic relations, the actual observations might be greatly improved. As far as the temperature conditions are concerned, the observational methods are fairly well worked out for the present. In the future we shall need a thermo-integrator, the indications of which may bear some at least empirical relation to plant growth, but such instruments remain to be devised. As has been pointed out, the moisture conditions of the environment affect the activities of a plant through their influence toward increasing or decreasing its water content. Now, most plants—and *all* agricultural plants—derive water mainly from the soil and lose it mainly to the air. It is thus clear that, with proper consideration of soil conditions, the data of precipitation should furnish us with a valuable criterion for comparing climatic areas. Precipitation is easily measured and our information in this connection is fairly satisfactory. For the other factor of the moisture relation of plants, however, namely the power of the aerial surroundings to extract water from the plant, the climatic data which have been accumulated in this country furnish practically no information. The available measurements and averages bearing on this point are those of relative humidity (a somewhat artificial abstraction), pressure of water vapor, wind velocity, temperature and sunshine intensity. While the present method of measuring rainfall is self-integrating and leaves little to be desired in the way of improvement, the methods employed in measuring the water-extracting factors just mentioned all involve artificial manipulations before any climatic characteristics can be derived therefrom. Indeed, the sunshine data furnished by the weather observatories is not even quantitative in any adequate sense.

In the face of these difficulties ecology has been forced to turn entirely away from the available meteorological data. It is apparent at once that the water-extracting power of the aerial environment is effective through the evaporating power of the air and the intensity of sunlight. The sunlight factor appears frequently to be of comparatively little importance in the climatic moisture relation, though its effects in removing water from moist objects such as plants can now be measured and automatically integrated with considerable readiness.[4] The evaporating power of the air (a complex of the effects of vapor pressure and wind movement) appears, on the other hand, to be generally of prime importance. This fact has long been recognized and meteorologists outside of the United States have accumulated a vast amount of information upon evaporation as a climatic factor.[5] Meeting with difficulties in the standardization of atmometers, many workers have turned their attention to attempts to derive a formula by which evaporation might be computed from the meteorological factors usually measured. An enormous amount of work has been done in this line, but the results are of little value for climatological purposes. At the same time various students of climatology and of plant activities have devised numerous forms of atmometers, for measuring and automatically integrating the evaporating power of the air directly. Since the latter is a very complex factor, it comes about that data from different kinds of instruments cannot be readily reduced to a common standard, so that there has been some hesitation in making evaporation measurements a general feature of climatological work. It is nevertheless true that, for our present purposes at least, all that is required is that some one form

[4] Livingston, B. E., "A Radio-atmometer for Measuring Light Intensities," *Plant World*, **14**: 96–99, 1911; "Light Intensity and Transpiration," *Bot. Gaz.*, **52**: 418–438, 1911.

[5] In this connection see Livingston, Grace J., "An Annotated Bibliography of Evaporation," *Mo. Weather Rev.*, **36**: 181–6, 301–6, 375–81, 1908; **37**: 68–72, 103–9, 157–60, 193–9, 248–52, 1909. Also reprinted and repaged 1–121, 1909. The subject has very recently attracted much more attention than formerly, especially from agriculturalists and ecologists.

of atmometer be generally adopted, and many weather services are at present furnishing data upon evaporation as well as upon the other climatic factors more commonly recorded. On account of various difficulties arising from the use of a free water surface for measuring evaporation, the most valuable instruments now available determine the evaporation rates from the surface of an imbibed solid, such as bibulous paper or porous porcelain. For plant ecology the porous cup atmometer[6] appears to be the most satisfactory of these instruments, and it seems to be rapidly rising in the esteem of agriculturists and others who are interested in this line of study. This instrument has the advantage, for our purpose, that its evaporating surface is so exposed as to be fairly comparable to the evaporating surfaces of plants.

The only systematic information which the United States Weather Bureau has furnished upon the geographical distribution of evaporation intensities is comprised in the report of Russell's[7] studies. This author employed Piche atmometers at nineteen stations and derived a formula from the results thus obtained, by which the monthly evaporation rates for many other stations were derived. His operations extended over a single year, from July, 1887, to June, 1888, and a very valuable chart of evaporation in the United States resulted therefrom.

During the summers of 1907 and 1908 I carried out a comparative study of evaporation intensities throughout the United States, under the auspices of the Department of Botanical Research of the Carnegie Institution, using the standardized porous cup atmometer.

[6] On the porous clay atmometer, see:

Babinet, J., "Note sur un atmidoscope," *Compt. Rend.*, **27**: 529–30, 1848. Marié-Davy, H., "Atmidomètre à vase poreaux de Babinet," *Nouv. Met.*, **2**: 253–4, 1869; Mitscherlich, Alfred, "Ein Verdunstungsmesser," *Landw. Versuchsstat.*, **60**: 63–72, 1904; also **61**: 320, 1904; Livingston, B. E., "The Relation of Desert Plants to Soil Moisture and to Evaporation," Carnegie Inst. Wash. Publ. 50, Washington, 1906; "A Simple Atmometer," *Science*, N. S., **28**: 319–20, 1908; "A Rotating Table for Standardizing Porous Cup Atmometers," *Plant World*, **15**: 157–62, 1912; also other literature there referred to.

[7] Russell, Thomas, "Depth of Evaporation in the United States," *Mo. Weather Rev.*, **16**: 235–9, 1888.

The results of these studies have been published[8] and furnish, for fifteen weeks only, the second chart of evaporation which has ever been prepared for this country. It is interesting to note that a fifth of a century elapsed between these two studies, and that nothing further has yet been attempted.

Judging from the results already obtained, it appears that the simple measurement and automatic summation of the evaporating power of the air for the various climatic areas furnishes as satisfactory a measure of the water-extracting power of the environment as the student of plant relations can hope for from a single condition, and the future development of this branch of science will depend largely upon whether or not comparative evaporation records may become available.

Treatment of observational data.

The frostless season.—In the preceding paragraphs have been considered the most requisite methods for obtaining climatic observations. We shall now turn our attention to the application of these observations after they have been obtained. It is the custom of meteorologists to derive from the actual observations, daily means, monthly means and annual means, and to give most attention to the latter. Now, for the purposes of vegetational-climatic investigations, it appears that none of these means offers much assistance. In the determination of plant activities, at least in the majority of cases, the controlling climatic factors are primarily effective only during the growing season, and I am convinced that this season should form the basis of a large part of the manipulation of climatic records, which which we are here interested. As an approximation of the vegetational growing season, for general use throughout our country, it seems most promising to adopt the length of the frostless season, the number of days intervening between the average dates of the last killing frost in spring and the first in autumn. That other duration factors will be required in many cases is not to be doubted,

[8] Livingston, B. E., "A Study of the Relation between Summer Evaporation Intensity and Centers of Plant Distribution in the United States," *Plant World*, 14: 205–22, 1911.

but this appears to be far more broadly applicable than any other. The actual data of mean length of the frostless season in the United States have never been published, but Day's chart (already referred to) presents a general view of the range in length of this period which this country affords. Data corresponding to those from which Day's chart of the frostless season was compiled have been deduced from the average dates of last and first killing frosts as given in the 106 Sumaries by Sections[9] published by the Weather Bureau. These deduced data have been used in deriving the other climatic indices considered below.

Temperature integration.—The mean length of the frostless season is of course primarily a temperature condition, but it tells us nothing of the normal temperatures which may prevail within the period designated, only that killing frosts do not normally occur. In order to be able to relate the temperatures of the frostless season to plant activities it is thus obvious that we shall need to sum or integrate the temperatures over the period of active growth. As has been said, the mature plant itself is to be regarded as a summation of all of the accelerations and retardations which have occurred during its life, so that our integration of temperatures should attempt to consider these, not merely as they affect our thermometers, but rather *as they affect plants.* This is, however, practically impossible until we have at our disposal a much larger fund of information concerning the general relation of plant activities to temperature, and such information is not apt to be forthcoming until such time as the laboratory for controlled conditions, mentioned above, may become a fact instead of a mere dream. Various procedures of temperature integration have been devised by different writers and appear to be more or less valuable in this connection, but the physiological basis for such procedures remains still to be established. Under the circumstances, it seems best here to give attention to but a single one. This is the method of direct summation of the daily normal means throughout the period in question.

[9] "Summary of the Climatological Data of the United States, by Sections," U. S. Department of Agriculture Weather Bureau. No date. The 106 pamphlets appear to have been prepared about 1909–10. The data extend for the most part through 1908 or 1909.

Bigelow[10] has given us the daily normal temperatures throughout the year for 177 stations well distributed over the country. This excellent piece of work has laid the foundation for many kinds of climatological study that would otherwise be impossible. The data are generally based on an observation period of about thirty years and may be regarded as quite as reliable as any other data that we now have. In summing the daily normal temepratures for the days within the average frostless season, for each one of the numerous stations, some temperature must be assumed as a starting point. I have taken 32° F. The results of such summations may be termed average or normal temperature summations, above 32° F., for the frostless season at the various stations.

The method here used is somewhat similar to that employed by Merriam[11] in his well-known study of the temperature relation in the United States. This author did not use the average length of the frostless season, however, and his manipulations differed from my own in other details. The general method of summations is not at all new, having been long employed by phenologists.

When we plot the temperature summation indices upon a map and draw isoclimatic lines in the usual way, there results a chart which presents the country divided into zones or bands. Such a chart is shown by the dotted lines of plates IX., X., and XI. Without entering into details, it is at once seen that the temperature summation zones cross the continent in a generally west-east direction, being southwardly displaced in the regions of the two mountain systems and also to some extent along the Pacific seaboard. Practically all of the area of the United States is characterized, according to this chart, by normal temperature summation indices ranging from 3,000 to 13,000. The southern half of the Florida peninsula exhibits still higher indices.

Integrations of the moisture relation. 1. General considerations.—While temperature furnishes us a single means of studying

[10] Bigelow, F. H., "The Daily Normal Temperature and Daily Normal Precipitation of the United States," U. S. Dept. Agric. Weather Bureau Bulletin R, 1908.

[11] Merriam, C. H., "Laws of Temperature Control of the Geographic Distribution of Animals and Plants," *Nat. Geog. Mag.*, **6**: 229–38. 1894.

both the tendency of the plant to gain heat and its tendency to lose heat, we find no such simple climatic factor to use in studying the conditions which tend to add water to the plant or to remove it. As has previously been mentioned, the ordinary plant derives most of its moisture supply from the soil and loses water to the air. The possible rate of moisture supply to growing plants is thus determined by the resistance of the soil to the movement of moisture into plant roots. While the physical properties of the soil play an important part in this connection and while these vary from place to place, the amount of water present in the soil is also of primary importance. This depends, for any particular soil and in the majority of cases, upon precipitation, and the measurement of this climatic factor furnishes us, as is commonly recognized, with a criterion of considerable value in the comparison of climatic areas. While the distribution of rainfall throughout the period of the plant's activities is fully as important as its amount, I shall give attention in this paper only to the latter.

It has already been emphasized that the evaporating power of the air is the main climatic feature in the control of water loss from plants, as from other moist objects. If we add to this the water-extracting or desiccating power of the sunshine we have an exceedingly satisfactory measure of the water requirements of plants, for most of the water absorbed by ordinary plants is lost by transpiration. Here also I shall consider only the question of the mean evaporating power of the air throughout the period of the frostless season.

If we assume for the moment that soils are all alike in their physical properties, and if the moisture supply of plants be proportional to precipitation while the water loss is proportional to the evaporating power of the air, some relation obtaining between these two factors should be a direct measure of the vegetational water relation. Unfortunately for our study, the assumptions above made, especially the one regarding the physical properties of soils, are very far from true; yet certain physical types of soil are found in every one of the climatic areas which we are apt to encounter, and for any such type the relation just referred to should be of great value.

Thus, heavy clays occur commonly throughout the United States and the moisture relation of plants growing thereon may be approximately proportional to the relation of precipitation to evaporation. A similar proposition may hold for sandy soils. It is, however, to be noted that a sandy soil and a clay soil under the same climatic conditions ought not to be expected to possess the same power of supplying moisture to plants.

The relation of precipitation to evaporation was first emphasized as a climatic factor influencing vegetational distribution in the United States by Transeau,[12] who constructed a very interesting and valuable chart of the eastern portion of our country on the basis of the ratio of mean annual precipitation to the annual evaporation obtained by Russell for a single year. Another, and in some ways more satisfactory relation between rainfall and evaporation is the *difference* between these factors, precipitation *minus* evaporation. I have tested this as extensively as our extremely meager data on evaporation will allow. In the present paper attention will be confined to this index of difference for the frostless season.

We now turn our attention to three examples of the quantitative study of the moisture relations of the United States, resulting in the means of precipitation, of evaporation and of the difference between these two for the frostless season.

2. Amount of precipitation during the frostless season.—Bigelow has given us, by means of very ingenious and elaborate methods, a table showing the daily normal precipitation for each of 177 stations in the United States, and it is upon this valuable work that I have based all of my quantitative studies of rainfall. In the present instance, wherein the normal distribution of precipitation during the year will receive no attention, I have merely determined the average normal daily precipitation at each station throughout the frostless season. This gives a precipitation index which is at once seen to be definitely related to plant activities. Stations with high precipitation indices are situated in the humid regions, those with low indices are in the arid regions.

[12] Transeau, E. N., "Forests of Eastern America," *Amer. Nat.*, 39: 875–98, 1905; "Climatic Centers and Centers of Plant Distribution," Mich. Acad. Sci. 7th Ann. Rept., 1905.

When these indices are placed upon a map and isoclimatic lines are drawn in the usual way, we have the chart which is shown in full lines in plate IX.[13] The data are in terms of hundredths of an inch per day and their range of magnitude is from less than two to over sixteen hundredths. This is not a proper place for detailed discussion, but it is at once obvious that the precipitation lines of this chart tend strongly to take a north-south direction, thus crossing our isothermal lines and dividing the country into irregular climatic areas each of which might be defined by the use of these two systems of lines. As has been stated, the data from which both temperature and precipitation charts have been constructed are relatively very satisfactory, and it may be surmised that the combination chart here presented is fairly reliable as a general picture of the climatic conditions of the country as measured according to the method here set forth.

3. Amount of evaporation during the frostless season.—Russell's data on evaporation in the United States are for but a single year, and that not a calendar one. The probability of error introduced by assuming these data to be normal is very great, yet, as has been emphasized, these are the only data yet available, and we must either employ them or follow the custom of our Weather Bureau and ignore the important subject of direct evaporation measurements entirely. More to illustrate the value of evaporation records than with any thought that the details of the present study may be free from large error, I present here the results of an approximate determination of the mean depth of daily evaporation for the frostless season. It is to be noted that the data for the earlier months of the frostless season are from the summer of 1888, while those for the later months are from that of 1887, an unsatisfactory state of affairs made necessary by the exigencies of Russell's study.

Russell's published data are given by months, and, since the

[13] It is to be remarked that this and the two following charts attempt no more than an approximation to normal conditions. The lines are so placed, however, as to represent the data as these have been obtained. Where no stations are present topography has been used as an indication of the probable position of the lines. All of the data here employed will be published elsewhere.

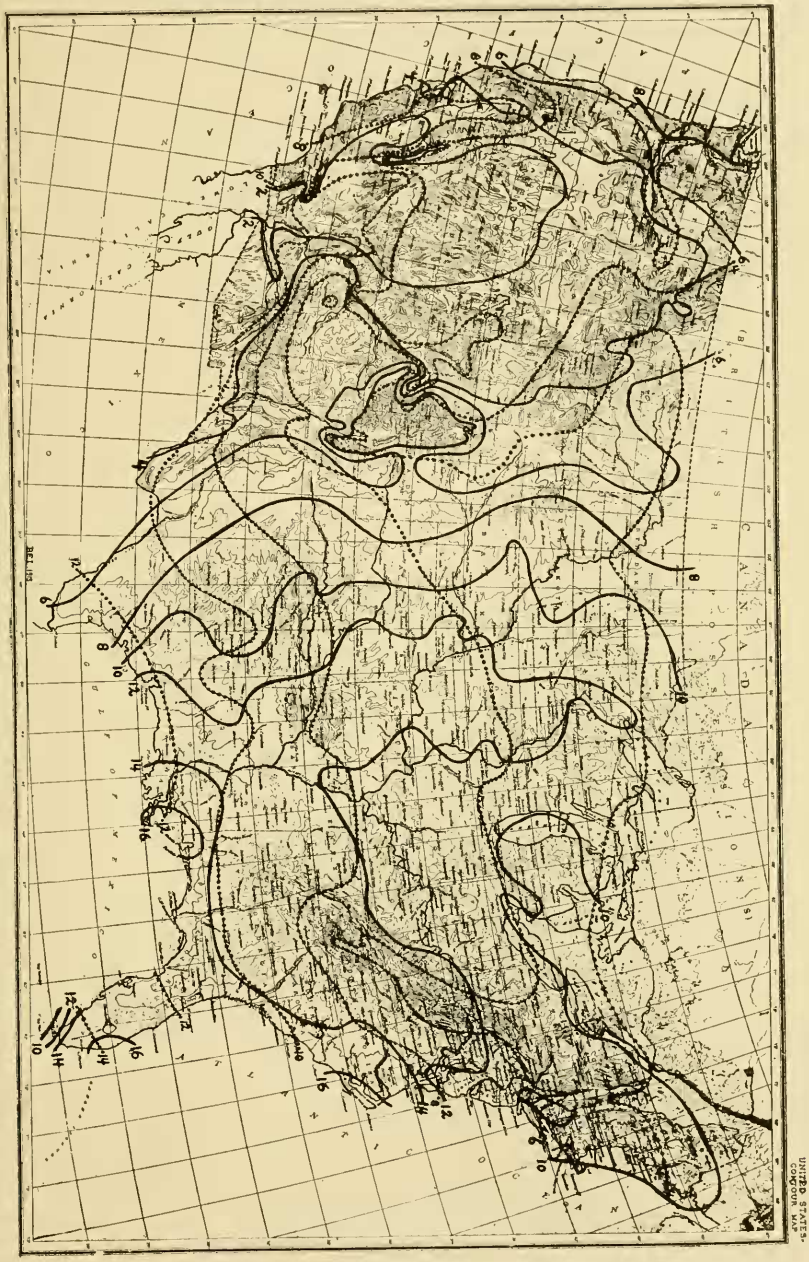

PLATE IX. Chart showing climatic mosaic formed by two systems of isoclimatic lines. Broken lines represent temperature summation indices (in thousands) and full lines show precipitation indices (in hundredths of an inch per day) for the mean frostless season.

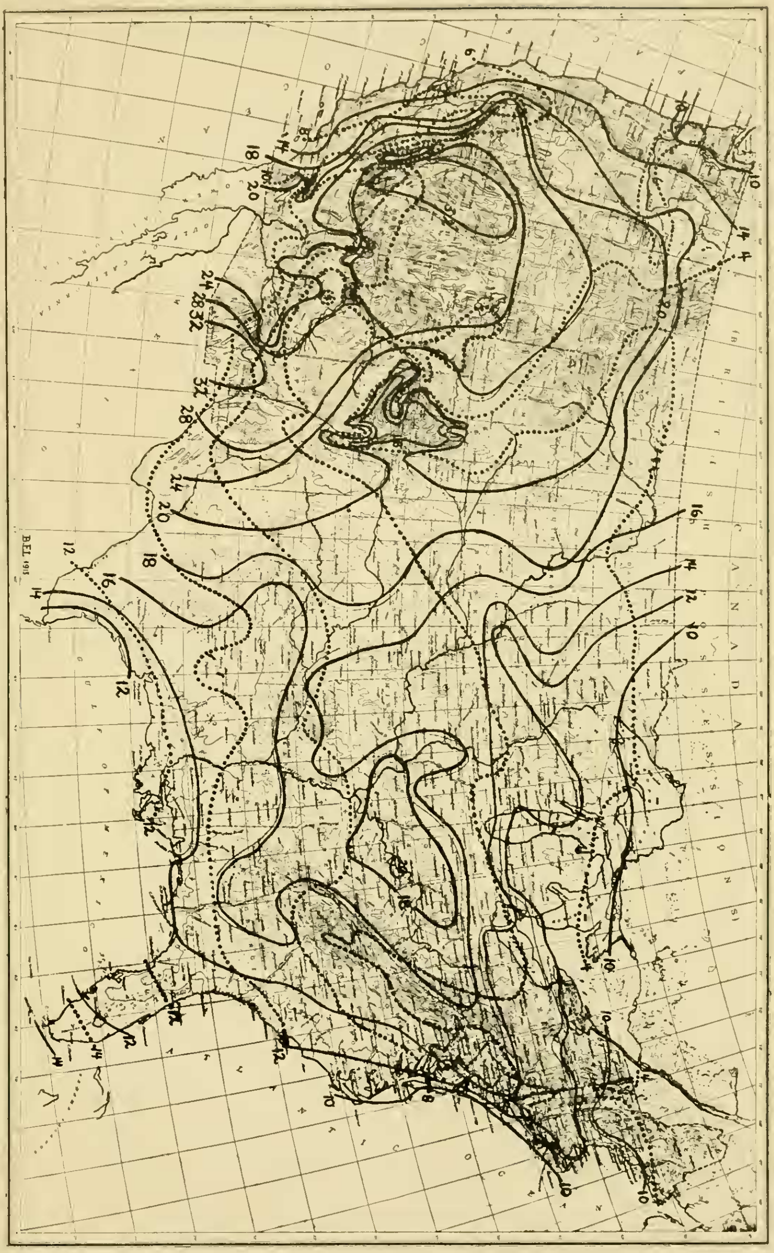

PLATE X. Chart showing climatic mosaic, as in plate IX, but the isoclimatic lines of temperature (broken) are here combined with a system of lines (full) representing evaporation indices (in hundredths of an inch per day) for the mean frostless season.

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